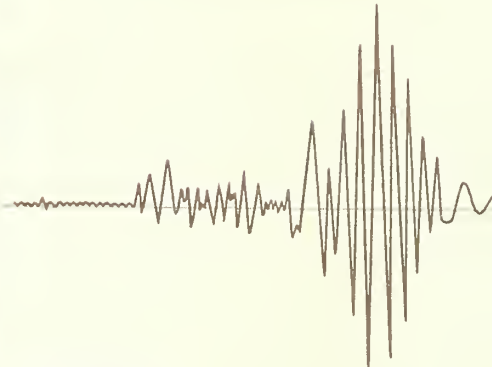


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THE NIGHT THE EARTH SHOOK

A GUIDE TO THE MADISON RIVER
CANYON EARTHQUAKE AREA

U.S. Department of Agriculture
Forest Service
Miscellaneous Publication No. 907
August 1962



Index map of the Madison River Canyon Earthquake Area.

FOREWORD

NEAR MIDNIGHT, in the quiet of a soft summer night, Mother Earth chose to reshape her mountains in violent response to deep-seated stresses no longer bearable. This was August 17, 1959. An eight-State area felt the first heavy jolt of the Hebgen Lake Earthquake, one of the strongest ever recorded in the United States. The heaviest damage and most spectacular impact of the earthquake occurred in southwestern Montana within the Gallatin National Forest.

Hundreds of vacationers were asleep in tents, camps, trailers, and lodges near Hebgen Lake and along the Madison River. Forest Service campgrounds were crowded long before dark; other campers simply pulled off the highway and set up their own camps near the river. And then, in the middle of the night, it happened.

Following the main shock of the earthquake, escape routes were blocked. A huge landslide sealed the lower end of the canyon. Slipouts in the highway skirting Hebgen Lake effectively stopped escape in that direction. Hours of darkness—hours of ordeal—faced most of the trapped vacationers.

Communication lines were out. First reports of the disaster came from a “ham” radio operator in badly damaged West Yellowstone. He had little knowledge of what had happened in the Madison Canyon. All that was known for sure was that there was chaos; there was a threat of flood; and there were trapped people desperately in need of help.

Help was on the way before dawn. Rescue units from many agencies in Idaho and Montana were on the move. At dawn a plane made a reconnaissance flight. Forest Service smokejumpers parachuted into the canyon to give first aid and to set up communications. Men on foot, on horseback, and in helicopters moved in to give assistance to survivors. Among the refugees themselves there were many outstanding acts of brotherhood and mutual help. Rescue workers treated the injured and evacuated them to nearby towns and ranches, where other volunteers provided food and shelter. By evening bulldozer roads had been built around highway slipouts; the immediate emergency was over, and all who wished to leave were able to get out of the canyon.

Some 34 Federal, State, county, and local agencies and organizations participated in the emergency work immediately following the earthquake. Neighboring States and Canadian Provinces offered further assistance. The search and rescue efforts of all groups, coordinated by Forest Service officers, continued until there could be no doubt that anyone was still stranded or lost.

A year later, on August 17, 1960, the Madison River Canyon Earthquake Area was dedicated by the former Chief of the Forest Service, Dr. Richard E. McArdle, “in memory of the events which took place here . . . as a dramatic example of earth-shaping forces . . . [and] for all its values . . . its resources, its geologic history,

and its deep human meanings.” Montana’s Governor J. Hugo Aronson unveiled a bronze plaque dedicated to the memory of the 28 men, women, and children whose lives were lost as a result of the earthquake.

Geologic events such as the Hebgen Lake Earthquake are keyed to geologic time—time in which man’s existence is no more than a fleeting moment. It is seldom that people have an opportunity to study such a dramatic display of natural forces.

Fortunately, and seemingly in answer to a geologist’s dream, a two-man party from the Department of the Interior’s Geological Survey was camped the night of the earthquake on a small knoll overlooking the northeast shore of Hebgen Lake. Dr. Irving J. Witkind, a professional geologist and leader of the party, quickly recognized that he was personally involved in a dramatic incident in the geologic history he had spent the summer deciphering. From his own notes and observations and later studies, Dr. Witkind has written and illustrated a layman’s story of the earthquake—its causes and results. He has interjected many eyewitness accounts of events. This is a nontechnical version, in contrast to the many scientific professional papers and reports already published or in process.

Dr. Witkind, with the approval of the Director of the Geological Survey, has graciously made his manuscript available to the Forest Service, U.S. Department of Agriculture, for publication. The Forest Service is grateful to Dr. Witkind and the Geological Survey, Department of the Interior, for the opportunity to publish his work. We believe that you, the reader, will find it helpful and meaningful when you visit the Madison River Canyon Earthquake Area—either in person or by means of this publication.

Edward P. Cliff

EDWARD P. CLIFF, *Chief*
Forest Service
U.S. Department of Agriculture

NOTE.—References in the text to “former highway 287” should now be read simply “highway 287” in reference to present roads in the area. The stretch of State Highway 287 which was inundated by Earthquake Lake has now been replaced by a new section of highway along the north side of the lake. On the index map the new highway roughly follows the edge of Earthquake Lake between Site 6 and Site 7.



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ACKNOWLEDGMENTS

The combined efforts of many members of the Geological Survey and U.S. Forest Service went into the preparation of this publication. We will all be gratified if it helps readers in visualizing what happened when the earth shook.

Some of the author's Survey colleagues who supplied information are J. B. Hadley, W. B. Myers, Frank Stermitz, F. A. Swenson, J. DaCosta, and R. C. Scott.

All of the photographs except two were furnished by the Department of the Interior Geological Survey.



THE NIGHT THE EARTH SHOOK

A Guide to the Madison River Canyon Earthquake Area

By Irving J. Witkind

Geological Survey, U.S. Department of the Interior
Denver, Colorado

INTRODUCTION

In the Hebgen Lake area, the night of August 17, 1959, was clear and a full moon illuminated the countryside. Hebgen Lake glistened in the moonlight, its surface calm and smooth. The resorts and campgrounds were filled with vacationers, many of whom were camped downstream from Hebgen Dam in the narrow confines of the Madison River Canyon.

At about 11:37 that night, at least three blocks of the earth's crust suddenly subsided, and a major earthquake was felt in the area. The ground lurched and trembled; man-made structures were fractured, and in places shattered and collapsed. People, shaken awake, rushed outside wondering what had happened. Many persons, stunned by the shock, gaped unbelievably at the newly formed features. Hebgen Lake, jostled by the abrupt drop, began to slosh back and forth in great waves, the first few of which were large enough to flow over Hebgen Dam.

In the Madison River Canyon near the Rock Creek campground, part of a mountainside was shattered by the major tremor, and for a few brief seconds hung poised over the unsuspecting, awakened campers. A few lay sleepily in their tents or trailers wondering what had happened; most assumed that the shaking of their tents and trailers was caused by bears. Several persons went out to investigate, but in the clear moonlight everything seemed normal. Suddenly—with a terrible roaring and grinding noise—the entire mountainside began to move. As the campers tried to flee, the avalanche slid into the canyon moving at nearly 100 miles an hour. People, cars, and trailers were crushed and buried. The survivors were knocked down by a violent air blast, and then some of them were engulfed by a huge wave of water from the displaced Madison River.

The only sounds in the subsequent dust-filled stillness were the cries of the injured and the anxious calls of separated families.

As the night wore on, clouds gathered and masked the moon. What had begun as a cheerful moonlit night had turned, in the space of seconds, into a night of fear, consternation, and deep anxiety. Working in the

pitch-black darkness to rescue the trapped and injured, survivors of the catastrophe constantly felt the earth trembling beneath their feet as repeated aftershocks shook the area. Boulders and rockfalls could be heard tumbling down the mountainsides.

When day dawned, the immensity of the landslide became apparent to the chilled and shaken watchers huddled on the slopes, but it was a long time afterward before the toll of human life was established. No one knew how many people had been camped in and near the Rock Creek campground prior to the disaster. Months afterward, many residents still had not grasped the magnitude, nor the absolute reality of the geologic changes wrought during those seconds when the earth quaked.

PATTERN OF GEOLOGIC EVENTS

At the time of the earthquake, two field parties of the Geological Survey were working nearby. Geologists J. B. Hadley and W. D. Long were at Ennis, Mont., about 65 miles northwest of Hebgen Lake, and Geologists I. J. Witkind and J. B. Epstein were camped on a small knoll overlooking the northeast shore of Hebgen Lake.

Witkind was abruptly awakened by the shaking of his trailer. His first thought was that the trailer had somehow slipped off its jacks, overridden the wheel chocks, and was now jouncing down the hill. Stumbling outside, he saw that the trailer was in place, but that nearby trees were whipping back and forth, their leaves rustling as if moved by a strong wind—but there was no wind! Suddenly he realized that it was an earthquake, and that he was personally involved in a dramatic incident in the geologic history he had spent the summer deciphering.

The Major Landforms

The Earthquake Area consists of two parts, separated by the newly formed Earthquake Lake (index map). The eastern part, about 8 miles north of West Yellowstone, is reached via U.S. Route 191 and former highway 287. The western part, about 35 miles from West Yellowstone, is also reached via former State Highway 287.

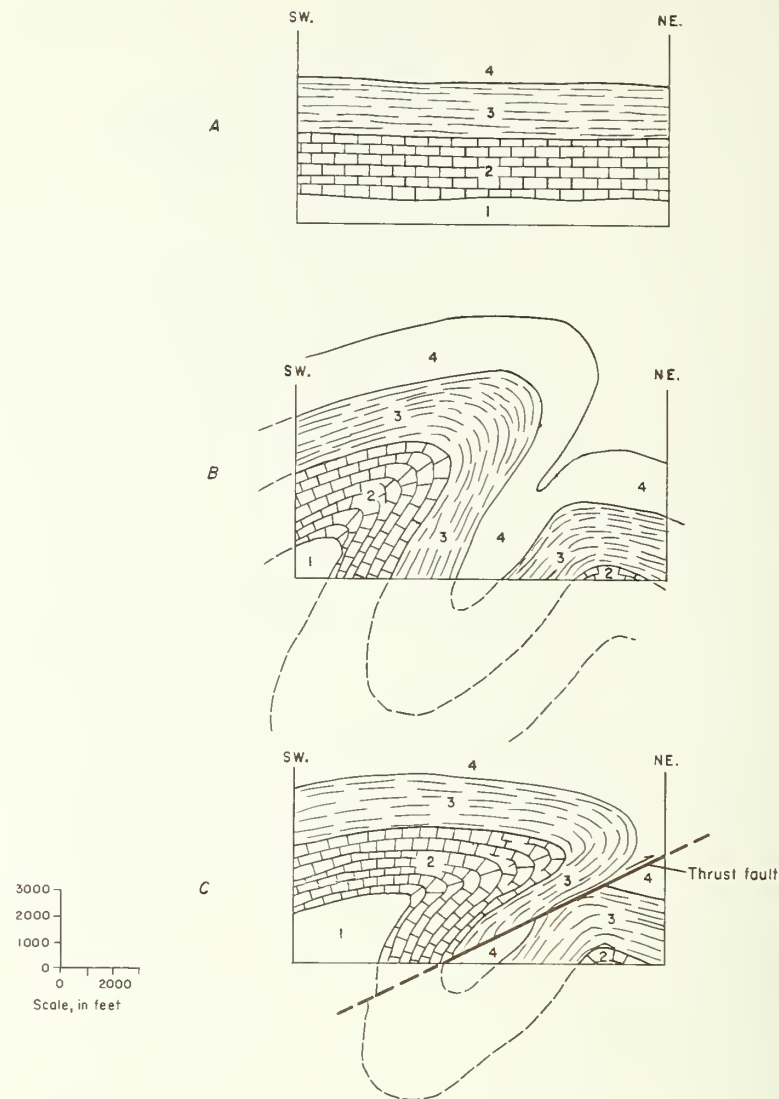
The eastern part, the heart of the Earthquake Area, includes the crudely circular West Yellowstone basin. The basin is rimmed on the west and southwest by the towering, rugged Madison Range and on the north by much less imposing mountains and hills. It is these heights that contain most of the features in the eastern part of the Earthquake Area. The Madison River, which drains the basin, flows westerly through a deep and narrow canyon cut through the core of the Madison Range. In 1915, Hebgen Dam was constructed by the Montana Power Company across the eastern end of the canyon, and Hebgen Lake was formed. The lake is usually drawn far down during the winter, but is replenished and filled by spring runoff. The lake is maintained near its high-water mark during the tourist season, and it was near this high level at the time of the earthquake.

Deformation of the Hebgen Lake Area

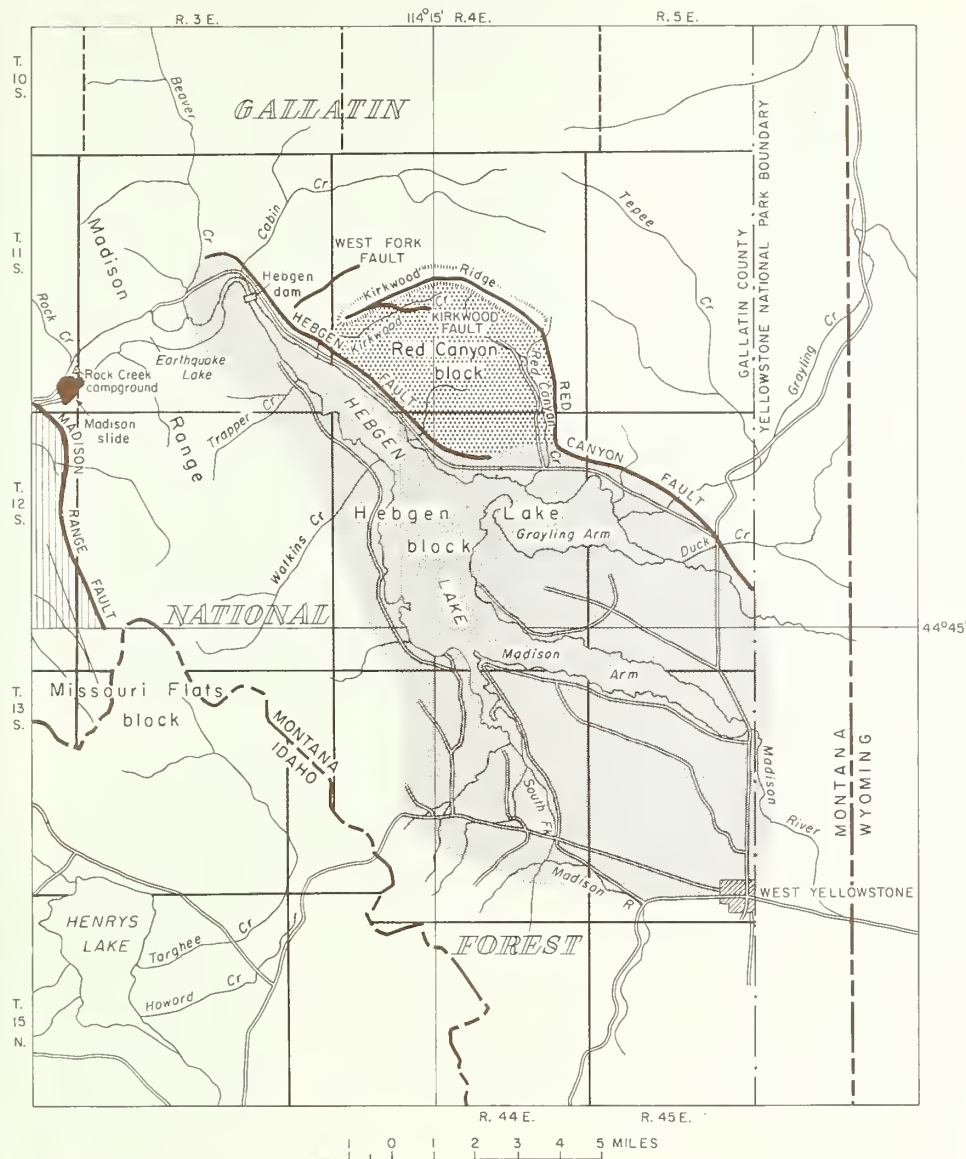
The bedded rocks north of Hebgen Lake have been bent and broken in at least two episodes of mountain building. The first episode probably began 70 to 75 million years ago and continued for millions of years. During this time the rocks that were once nearly horizontal were folded, tilted on end, or turned over. Some were so tightly folded that they broke and formed thrust faults. Kirkwood Ridge and Hebgen Ridge (index map) are remnants of overturned folds, and the steeply inclined beds that form these ridges are easily visible from former State Highway 287 or adjacent trails.

About 60 million years ago the compressive crustal forces were gradually stilled and this first episode slowly came to an end. Erosive forces continued to shape and change the landscape, but the crust itself was stable. Then, beginning about 20 million years ago, a second episode of mountain building started—one that has continued intermittently to the present. The region was slowly arched and raised, stretching the rocks until they sagged or broke; here and there, blocks of the earth's crust began to sink along marginal faults (p. 7).

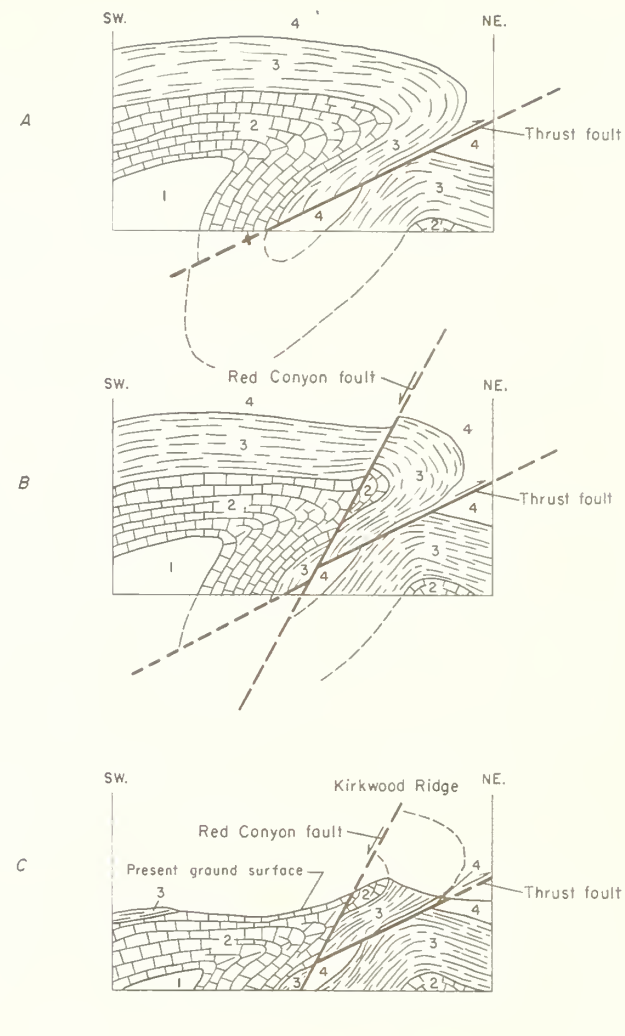
Two such subsided blocks are in the Hebgen Lake area (p. 7). The Red Canyon block, about 20 square miles, is much smaller than the Hebgen Lake block, with an area of about 125 square miles. Each of these blocks is bounded on its north edge by one or more long-established faults; the Red Canyon block is outlined in part by the Red Canyon Fault, and the Hebgen Lake block is bounded on the north and northeast by the Hebgen Fault and by part of the Red Canyon Fault. In fact, the Red Canyon block can be considered as a small, partly separated segment of the Hebgen Lake block. A third such block, the Missouri Flats block, is west of the Madison Range near the mouth of the Madison River Canyon.



Diagrammatic sketches illustrating the formation of overturned folds and thrust faults. A, Beds are nearly flat shortly after being laid down and solidified. B, As the beds are pushed by horizontal forces, they yield and form huge overturned folds. C, As compression continues, the overlying beds tear and the upper plate of rocks is thrust over the lower plate. The surface along which the rocks moved is known as a "thrust fault."



Two large fault blocks in the Hebgen Lake area. The western, southern, and eastern margins of the Hebgen Lake block are uncertain.



Blocks of ground, first compressed into folds, are further modified by block faulting. A, The final result of an episode of folding. This sketch is the final stage represented on p. 6. B, The folded rocks are broken by a fault, and the block of ground south of the fault is dropped. C, Continued spasmodic dropping of this block south of the fault finally results in a ridge underlain by strata on edge or overturned. The ridge is bounded on both north and south sides by faults. Kirkwood and Hebgen Ridges were formed in this fashion.

In the past, each block has been dropped repeatedly—and unevenly, the north side going down the most. Every time the blocks dropped, an earthquake resulted, and at times new small cliffs—fault scarps—were formed which coincided with or were near the old faults. The layers of rock in the dropped blocks have been warped, but in general the successive northerly tilting of these blocks has inclined the beds to the north. After each movement, there has been a long period of quiet during which the fault scarps have been eroded, and evidence of the abrupt movement has been more or less concealed.

Apparently this repeated dropping and tilting of huge blocks of ground had not occurred in the Hebgen Lake area in recent time (although it had in the Missouri Flats), for none of the inhabitants were aware that they were in an active earthquake area.

THE EARTHQUAKE

At about 11:37 on the night of August 17, 1959, geologic history was repeated and the two blocks in the Hebgen Lake area dropped and tilted toward the north. At the same time the Missouri Flats block, west of the Madison Range, dropped, but not so far. And it is possible that a part of the Madison Range between the Hebgen Lake area and the Missouri Flats basin was also bowed down somewhat. As the masses of rock scraped past one another a major earthquake resulted, and fresh scarps facing valleyward appeared either along or parallel to the concealed faults.

In the Hebgen Lake area, the scarps face southward and reflect renewed movement on the Red Canyon and Hebgen Faults (sites 1 and 4 of the Earthquake Area). West of the Madison Range, two small scarps, facing westward, resulted from movement on the Madison Range Fault.

The downward movement along the faults probably occurred as a rapid grating of one rock mass past the other, rather than as a smooth swift sliding.

Mr. Wells Morris, Jr., owner of the Parade Rest Ranch, which is on the dropped Hebgen Lake block, was asleep at the time of the major shock. He was awakened by the distinct sensation that his bed was dropping out beneath him in short spasmodic jerks—a clear indication of how the south block was dropping. Had the block of ground underlying the Parade Rest Ranch been raised, Mr. Morris probably would have felt the bed pushing him up in short rapid impulses.

How long the earth shook during this first major shock is not known; estimates range from 5 seconds to 2 minutes.

When the Red Canyon block (p. 7) dropped and a fresh scarp appeared along and near the trace of the Red Canyon Fault, relatively little damage was done. Trees fell where uprooted by the scarp. There were several landslides and rockfalls. Boulders were dislodged and ricocheted down

Left: Fresh fault scarp formed at the time of the major tremor. This scarp can be easily examined in Red Canyon (site 1 of the Earthquake Area).

Right: Aerial view of Hebgen Dam taken in early September 1959, as repairs were under way. Gullies in the earthfill, resulting from the successive inundations of the dam, are still visible. No water was being discharged through the spillway at this time. All discharge was through the tailrace shown in the lower right-hand corner of the photograph.



the slopes, smashing paths through the trees and gouging pits in the ground wherever they struck.

In sharp contrast was the destruction wreaked when the Hebgen Lake block dropped. Here the major damage stemmed from the action of Hebgen Lake. The abrupt downward movement with its attendant vibration jostled the lake and it began to slosh back and forth in great oscillations.

One family, camped in a small house trailer along the north edge of the lake, was awakened by the major tremor. Shortly after, they were dismayed to find that the lake—which had been 50 feet away—was now swirling around their trailer! They hurriedly stumbled from the trailer, and then scrambled to higher ground and safety. When they looked back the trailer was floating away, with only the raised hatch cover still visible.

THE SEICHE

The backward and forward sloshing of the lake, known as a seiche (pronounced “saysh”), continued for about 11½ hours. The cycle (or period) of the seiche—the time needed for the water to wash onto one shore, withdraw, and then return—was about 17 minutes. The first surges were so strong that they flowed over Hebgen Dam.



Mr. George Hungerford, foreman at the dam, and his assistant, Mr. Lester Caraway, were both awakened by the major tremor and recognized it as an earthquake. Worried that the dam might be leaking, both men (accompanied by their wives) hastened to a nearby water-measuring gage directly downstream from the dam. As they neared the gage, they heard a roar, and glancing up saw a wave of water about 4 feet high coming downstream. Fearful that this was a first stage in the collapse of Hebgen Dam, the two couples raced for the high ground near the dam. When they arrived, the downstream side of the dam was wet! They watched the lake level rise gradually until the crest of the dam was submerged beneath a 3- to 4-foot-deep wave of water which kept flowing 5 to 10 minutes. The water then subsided, and the crest of the dam reappeared. Shortly thereafter, the dam was again inundated, but this time the wave was smaller and the dam was not submerged as long.

Hungerford observed that the dam was crested four times. During one withdrawal, both men raced onto the crest of the dam, looked down on the reservoir side, and could see no water!

Summer residences and motels close to the lake were damaged when the Hebgen Lake block dropped. On the south shore the damage was confined chiefly to fallen chimneys and broken and disrupted masonry. By contrast, on the north shore, where the ground moved more, many cabins were tilted, wrenched askew on their foundations, and otherwise damaged. Shortly thereafter, the seiche began to move past or over some of these cabins, causing more damage (pp. 10, 11).

One resort that was completely destroyed was Hilgard Lodge, along the northeast shore of Hebgen Lake, and about 1 mile southeast of Hebgen Dam (index map). During the major shock, the ground around Hilgard Lodge was rent by fissures, and patches of ground began to slump into the lake. Segments of one access road slid into the lake and all buildings were severely shaken and tilted. Additional blows were dealt by the seiche as it moved toward and away from Hebgen Dam. Mrs. Grace Miller, owner of the resort, was awakened by the major shock, and within moments realized that her residence was slowly sliding into the lake. Dazed and stunned, she scrambled out of the house to safety, leaving behind all her possessions. Tediously and laboriously, guided by her dog, she made her way across sage-covered hills to the Kirkwood Ranch, about 1½ miles to the south. In a few cataclysmic moments, she had lost much of the work and savings of a lifetime.

NORTHWARD DISPLACEMENT OF HEBGEN LAKE

When the lake quieted, it became apparent that the northerly tilt of the Hebgen Lake block had displaced the lake northward. The north shore was flooded; jetties, docks, and beaches were submerged (p. 18). By contrast, the south shore emerged, so that stranded boats and docks were common sights and immense areas of bay and lake bottom were exposed (p. 11).

When the lake was displaced northward, it occupied a changed reservoir whose capacity exceeded that of the former lake basin. Consequently, the water level dropped about 0.7 foot as soon as the lake quieted. Water gages downstream showed that the drop was not due to water that had sloshed over the dam as a result of the seiche, and soundings failed to disclose any concealed fault in the lake bottom that might have increased its capacity. So the greater capacity of the new basin must be the result of the warping of the Hebgen Lake block.

HEBGEN DAM

Hebgen Dam is 721 feet long and rises 87 feet above the river floor. The dam and the ground on which it rests were dropped about 10 feet during the main tremor. The drop with its attendant chattering, plus the slump of unconsolidated rock debris on which the northeast abutment of the dam rests, and finally the action of the seiche, all subjected the dam to stresses for which it was not designed. Despite this, the dam held firm although rumors were rife during the first days after the earthquake that its collapse was imminent or had even happened.

Though it did not fail, the structure was heavily damaged. The concrete core was cracked in at least four places, and locally tilted and twisted out of line (p. 12). The concrete spillway was cracked but still intact, although one of its piers was pushed askew. The earthfill on both sides of the concrete core had settled unevenly, the greatest settlement (about 5 feet) being at the northeast end.



Left: Aerial view of Hilgard Lodge showing intense fracturing of ground, and partial submergence of motel units. Main dwelling has slid into lake and floated away.

Right: Inundation of lake front at Hilgard Lodge.



Bottom left: Crumpled and disrupted motel unit at Hilgard Lodge.

Bottom right: Interior of cabin at Hilgard Lodge showing the dark water lines of the seiche on the walls above the wood paneling. The water lines indicate degree of tilting of the cabin; this one was but slightly tilted.





Aerial view looking northwest toward Hebgen Dam showing the submergence of the northwest arm of Hebgen Lake.

Top left: Roof of main dwelling of Hilgard Lodge at landslide about half-a-mile northwest of Hilgard Lodge.

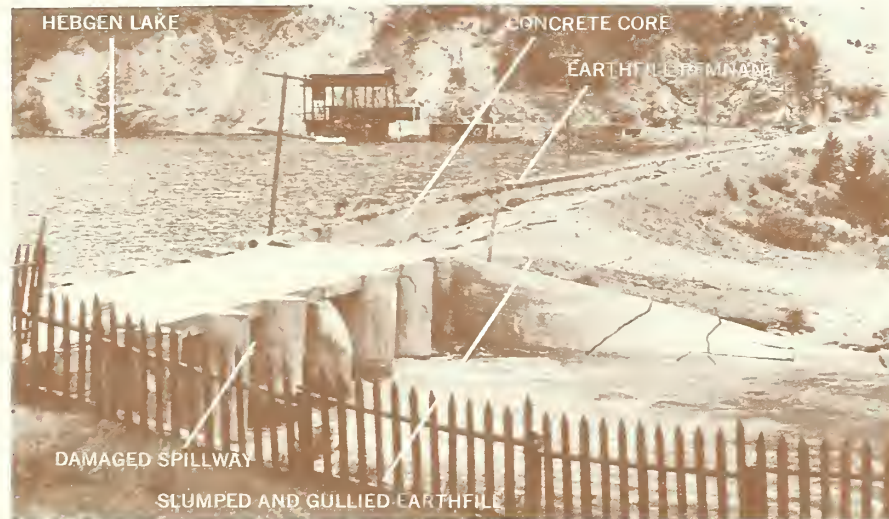
Bottom left: Stranded docks and launching mats along the south shore of Hebgen Lake; summer residences are concealed by trees.

THE MADISON SLIDE

Downstream from the dam, State Highway 287 and the Madison River occupied a narrow valley floor between steep, towering canyon walls. This particular sector of the canyon, from the dam downstream to the mouth, had always been a favorite camping site, and the Forest Service had constructed and maintained campgrounds along the highway.

On the night of August 17 all available space was filled, and most of the campers were asleep when the earthquake struck.

Within half a minute after the main tremor a major landslide occurred in the Madison River Canyon. The slide, about $5\frac{1}{2}$ miles downstream from the dam, buried an area directly west of the Rock Creek campground (p. 13).

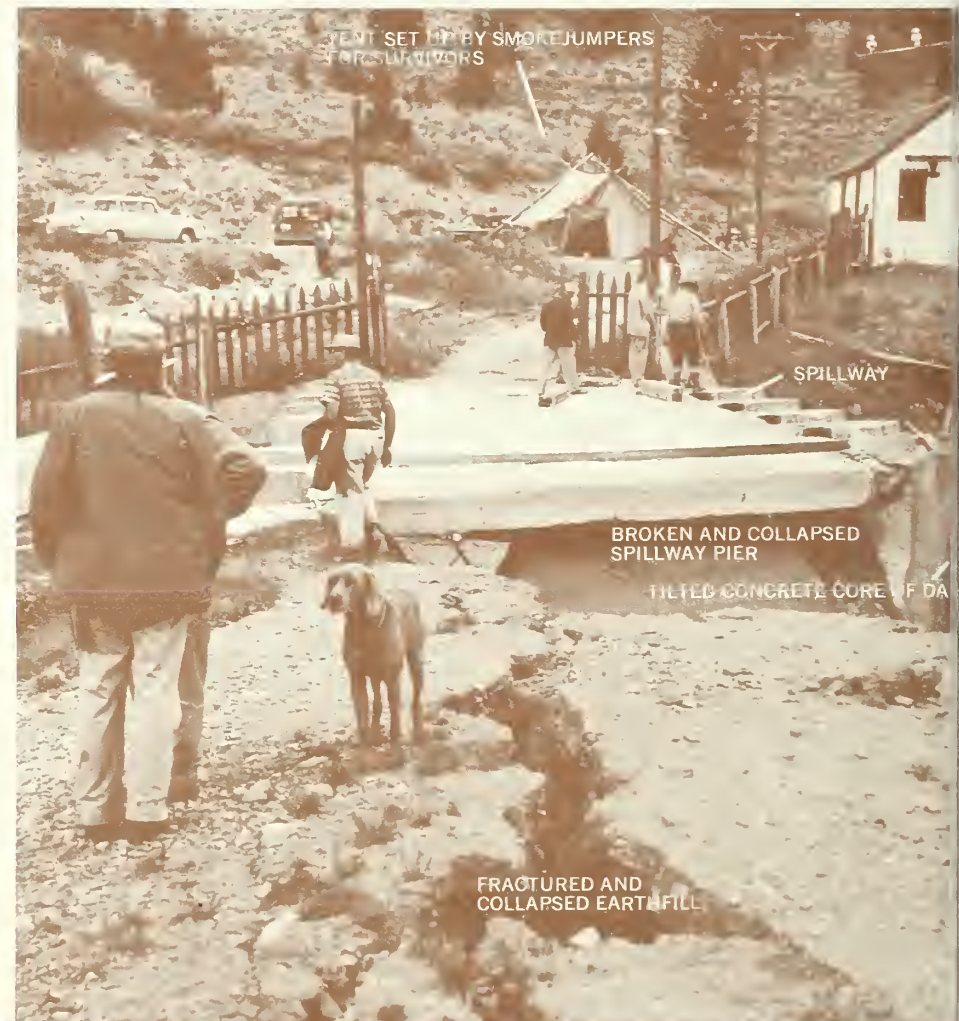


Damage to Hebgen Dam. Photographs taken on August 18, 1959, the day after the earthquake.

General view of Hebgen Dam showing uneven slump of earthfill away from concrete core.

Top right: Crack in concrete core; remnant of earthfill is still preserved on concrete core.

Bottom right: The collapsed earthfill and a damaged concrete spillway pier. The twisted and tilted concrete core shows along right edge of photograph. Originally the core was vertical and aligned with right edge of spillway.



The Lewis Smith family of Greeley, Colo., camped at the Beaver Creek campground, about 2½ miles downstream from the dam, were awakened by the major tremor. Cognizant of their precarious position below the dam, Smith hurried his family into their clothes, and drove away, abandoning his house trailer. At highway 287 he had two choices. He could turn northeast and drive toward the dam for 2½ miles until he reached the high ground near the dam; or he could turn southwest and drive 5 miles down and through the Madison River Canyon.

Smith decided to turn southwest. He drove down the canyon until halted by a large boulder in the road. Still fearful that the dam would break, the Smiths left the car and scrambled up the mountain flank to higher ground. They spent a cheerless night listening to boulders tumble down the mountainside. At dawn they saw that the boulder blocking their car was part of the immense mass of the Madison Slide.

Returning to the car, Smith heard a radio news report that the collapse of Hebgen Dam was imminent. He therefore drove his car as far as he could up a small knoll, and climbed back to his family.



The Smiths were rescued by helicopter the next day, August 18. The car was gradually submerged as the waters penned behind the slide rose to form Earthquake Lake.

When the slide came to rest, its northeastern (or upstream) edge was about 100 yards away from a campsite occupied by the Rev. Mr. E. H. Ost, and his family.

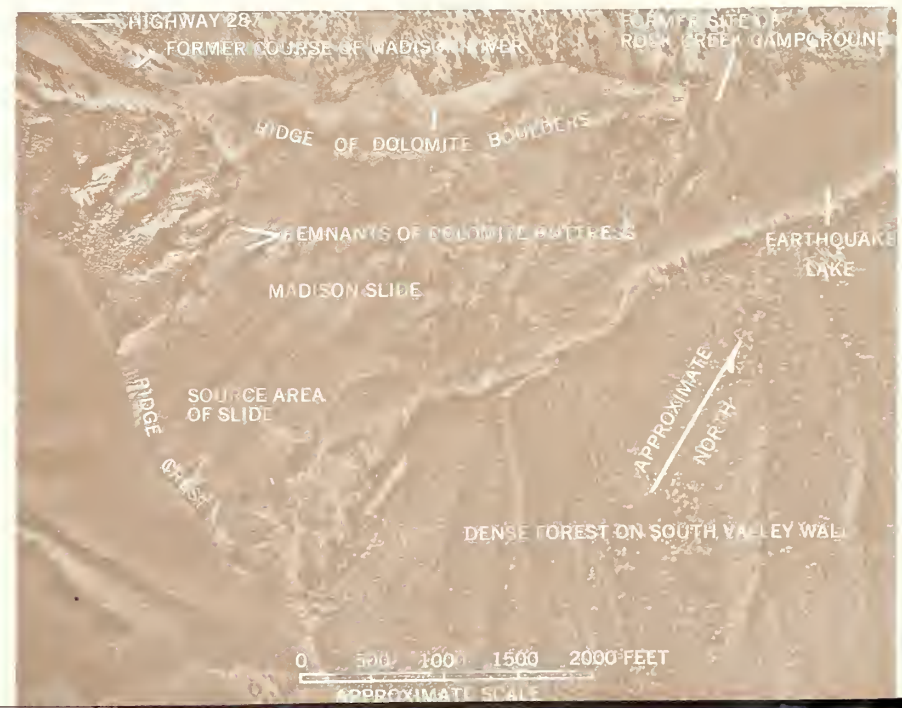
The Rev. Mr. Ost and his wife were awakened by the major tremor and stepped out of their tent to see what had happened. They stood in the moonlight for about 20 seconds looking about; then suddenly they heard a terrifying grinding and roaring noise intermingled with the sound of rushing water. Alarmed, Mr. Ost at first thought that a wave of water was coming downstream. None was; but when he glanced downstream he was astonished to see a wall of water racing toward him! He called to his family to hang onto trees and he and his wife did so while the water swirled around them. Their daughters fled about 50 feet and were not touched



by the water. When the wave had passed, Mr. Ost and his family struggled up the mountain flank away from the rising water. They were joined by other survivors and all were rescued the next day.

As the debris of the slide crossed the valley it almost instantly displaced the Madison River. This sudden change, like dropping a flat rock in a shallow gutter of water but infinitely more powerful and destructive, caused water to surge both up and down the canyon. The initial wave of water was strong enough to roll the Rev. Mr. Ost's car and carry it some 50 feet upstream. Tents in the area were crushed and swept aside and debris scattered far and wide.

Aerial photograph of the Madison Slide.



Within 6½ hours, the water impounded behind the slide had engulfed the cars left in the campground.

In all, 7 people were known dead as a result of this slide, and 19 more were missing—presumed buried beneath it.

One of the more tragic incidents involved the F. R. Bennett family of Coeur d'Alene, Idaho. Mr. and Mrs. Bennett and their four children, en route to Yellowstone National Park, reached the western end of the Madison River Canyon late in the afternoon of August 17 and decided to spend the night there. Mr. and Mrs. Bennett occupied their house trailer, while the children slept in bedrolls nearby. The Bennetts were awakened by the jiggling of the trailer and wondered what had caused it. Some time later, Mrs. Bennett recalls, she heard a tremendous roar, and



she and her husband, alarmed, left the trailer to check on the children. Suddenly they were struck by a violent blast of air. Mrs. Bennett saw her husband grasp a tree for support; then as his feet were swept out from beneath him, he was strung out "like a flag" for a moment before his hold was broken and he was blown away. Before Mrs. Bennett lost consciousness, she recalls seeing one of her children blown past her, and a car being tumbled along by the air blast.

Philip Bennett, her son, was buffeted by the wind and washed downstream by a wave of water. Although his leg was broken, Philip managed to crawl into a clump of trees, where he burrowed into the mud for warmth and awaited daybreak.

Mrs. Bennett and Philip, the only survivors, were rescued early next morning and taken to the hospital at Ennis, Mont.

About 38 million cubic yards of rock slid into the canyon from the south valley wall. The flank of a mountain, whose crest was about 1,300 feet above the river floor, broke loose, and the entire mass moved across the canyon as a sheet (p. 13). When the slide came to rest, its surface was still covered by soil and trees (p. 15), and the various rock types were arranged as they had been on the mountainside.

The slide is about a mile long, and three-quarters of a mile wide; when emplaced it was about 225 feet thick (p. 15). The sudden emplacement of this immense mass of rock in the narrow confines of the canyon caused the air blast and the waves of water. J. B. Hadley of the Geological Survey, who studied the slide, estimates that it was moving about 100 miles an hour when it engulfed the camp areas. The momentum of the slide was such that its front rode about 400 feet up the opposite (north) canyon wall.

Near the Madison Slide the layers in the rocks on the south valley wall dip steeply valleyward. These rocks, thinly laminated, intensely altered and weathered, had a tendency to slide even before the earthquake, but were restrained by a jagged buttress of a hard crystalline rock called dolomite. A crude analogy would liken the weathered rocks to panes of glass leaning against a wall. The buttress of dolomite, to continue the analogy, could be considered as a block of wood fastened to the floor in front of the panes of glass, preventing them from sliding. As long as the wooden block remains in place, the glass panes cannot slide; once the block is removed, the glass panes are free to move. At the time of the major tremor, the already severely fractured dolomite failed. Part of the south mountainside broke free, slid into the valley, and was carried some 400 feet up the opposite mountain flank. The former dolomite buttress was at the front of the slide, and it is now a mass of white boulders on the north edge of the slide (p. 15) behind the parking area at site 7. A memorial plaque is on one of the largest of these boulders.

General views of the Madison Slide and its source area.

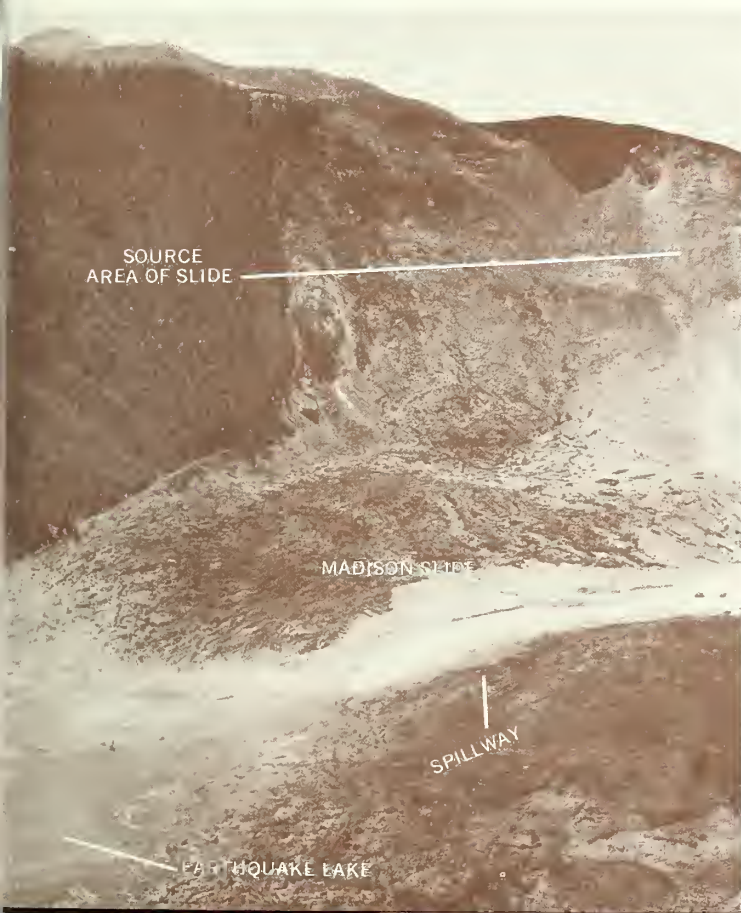
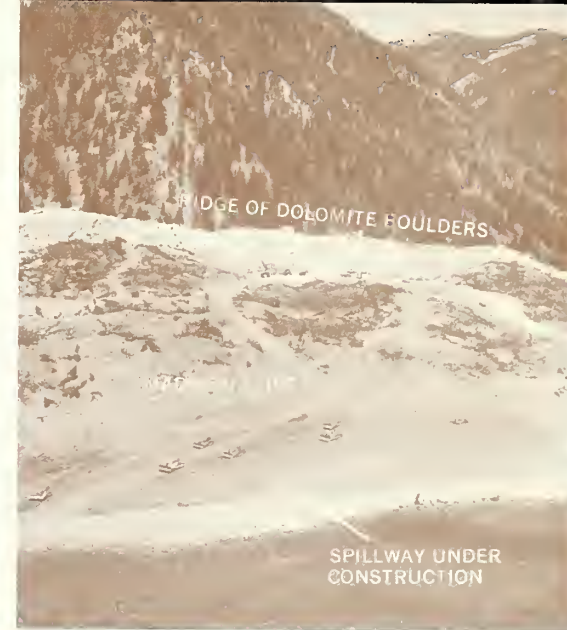
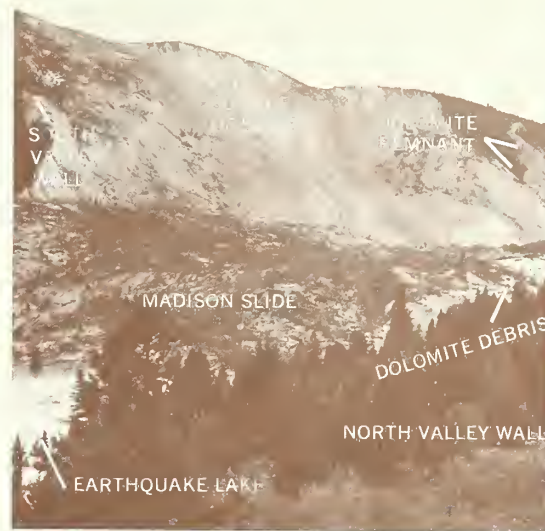
Top left: Aerial view of the slide's western (or downstream) edge. In the lower left-hand corner, the former course of the Madison River—now dry—is outlined by two parallel rows of trees. Earthquake Lake is in the center of the photograph. The light area in the right center is the new spillway under construction by the Corps of Engineers at the time the photograph was taken.

Top center: The eastern (or upstream) edge of the slide, and the source area. Broad face of inclined rock near crest of ridge indicates the steep angle at which the beds rested. This photograph, taken on August 19, shows the top of the slide covered by trees and soil. Earthquake Lake is not yet deep enough to conceal the standing trees.

Top right: The spillway under construction (area being worked on by tractors), and the dolomite ridge that marks the slide's north edge.

Bottom left: The eastern edge of the slide, and the spillway under construction.

Bottom right: Boulders of schist in the slide.



Once the valley was blocked, the waters that crested Hebgen Dam as a result of the seiche, plus the waters normally released through the spillway at the dam, were impounded east of the slide and Earthquake Lake began to form.



Mr. and Mrs. Grover Mault of Temple City, Calif., were almost drowned by the rising waters of Earthquake Lake. They spent a miserable, forlorn, and frightening night in the branches of a tree, watching the waters of the new lake slowly rise.

The sudden surge of water at the time of the slide trapped the Maults in their trailer. As they tried to escape, the rising waters carried the trailer about 200 feet upstream before lodging it against some rocks. Although the trailer was almost completely submerged by then, the Maults managed to clamber onto the roof. As the waters rose, they abandoned the trailer and climbed into a nearby pine. The ever-rising water forced them to move higher and higher where the limbs were smaller. Time after time, boughs broke and dropped them into the water. Each time they climbed back into the tree. Many who stood by helpless remember their repeated calls for help. During the night several attempts to locate and rescue the couple were made by Mr. Frank Martin of Virginia City, Mont.—who used an inflated air mattress in lieu of a boat! At daybreak Mr. Martin located a boat and helped the couple ashore. The Maults had spent more than 5 hours in the tree.

MINOR EFFECTS

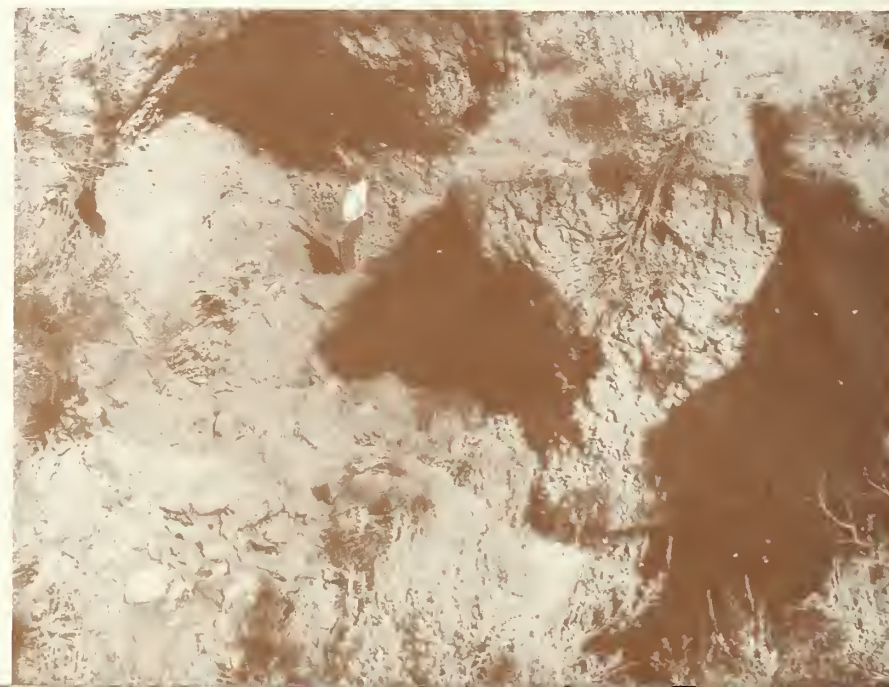
Sand Spouts

At the time of the major tremor, a series of minor related events added to the consternation and confusion. Of these the most interesting was the explosive birth of "sand spouts," chiefly in the sand and gravel along the north shore of Hebgen Lake (pp. 16-17).

Sand squeezed out along narrow fractures near Parade Rest Ranch.



Johnson Creek sand spout formed by explosion of sand and water near Hebgen Lake Lodge (site 2 of the Earthquake Area).





Sand spout near former highway 287 where it crosses Parade Rest Ranch.

Just after the principal shock, long, thin, gaping fissures opened in many fields, and began to discharge water and sand. In some places the mixture welled slowly out of the fissure; in others the water spouted several feet. Near Hebgen Lake Lodge (site 2, index map) the water pressure was so great that sand and gravel were ejected and long steep-walled craters were formed, one of which—the Johnson Creek sand spout—was about 50 feet long, 20 feet wide, and 9 feet deep. Cobbles as much as 6 inches across were thrown out.

After the first violent discharge, water and sand continued to ooze from the fissures for about 3 hours. Next morning only flat-topped piles of sand and silt along the fissures remained as testimony to these weird happenings.

These sand spouts are probably the result of shaking during the earthquake. The shaking compacted the loose sand and gravel, drastically reducing the pore space between grains. In the water-bearing layers, this squeezing put tremendous pressure on the minute droplets of water which filled the pores. Wherever a fissure (formed by the alternating compression and dilation of the ground due to the earthquake waves) tapped one or more of these water-bearing formations, the water pressure forced the water and sand to spew out and form a sand spout.

Mr. Frank Jans reports that on the night of the earthquake, water and sand were forced up within the casing of the water well at "The Narrows" resort so vigorously that the pump began slowly to rise. About 3 hours later when the water pressure decreased, the pump and its attached pipe had been raised some 8 inches above the concrete platform on which the pump had sat. As the pump rose, the mixture of water and sand was deflected by the base of the pump, and an umbrellalike shower resulted.

Minor Landslides

At the time of the earthquake, small and large masses of land along the north shore and northwest arm of Hebgen Lake slid into the water. Three of these landslides involved parts of former highway 287 and they effectively isolated the sector near Kirkwood Ranch and Hebgen Dam. All campers in the Madison River Canyon who fled eastward in hope of reaching route 191 were halted at a large scalloped alcove about 1 mile southeast of the dam (p. 11). This alcove is about 750 feet long and 200 feet wide; a third of a million cubic yards of debris slipped into the lake at this point.

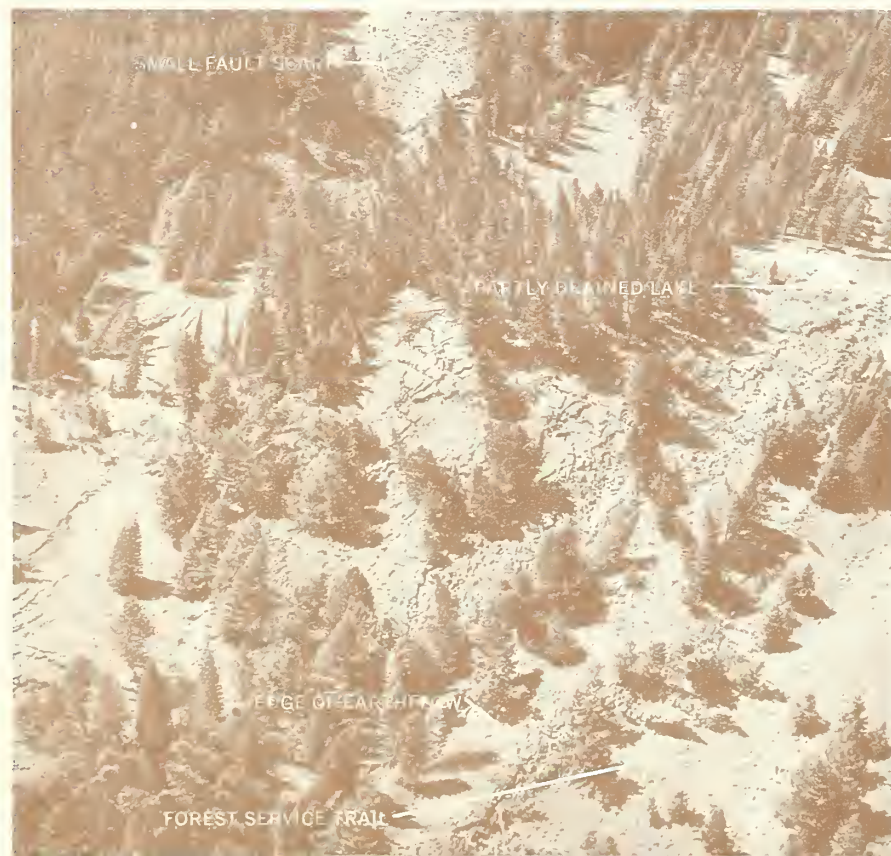
Much of the material that slumped was loose debris, and the underwater part of it was probably well saturated. This unstable material was easily set moving by the shaking during the major tremor.

Movement of Earthflow

Near the Parade Rest Ranch (index map), former highway 287 passes over the toe of a large ancient earthflow. The earthquake caused the earthflow to shift downslope slightly, and the highway was bowed southward about 3 feet. This bending of the formerly straight highway is especially easy to see from the bridge across Grayling Creek.

Farther northwest in Kirkwood Canyon near Kirkwood Ranch (index map) another ancient earthflow seemed to be undisturbed by the earthquake. Aerial photographs taken 4 days after the main shock show the earthflow to be whole and in place. On the fifth day, however, the earthflow began to shift downslope and cracks opened in the ground, disrupting trails and felling trees. Within weeks a large area was devastated as the flow continued to move downhill.

The Kirkwood Canyon earthflow at the end of August 1959. Slump has formed ground cracks, and caused the trees to tilt at all angles. Small lake, now partly drained, is at right edge of photograph. Small fault scarp is visible at top center of photograph.



A small forest fire broke out near Kirkwood Creek about a week after the earthquake. As several Forest Service men, dispatched to fight the fire, gingerly walked across the moving earthflow they could hear the ground creaking and groaning.

SURFACE WATER AND GROUND WATER CHANGES

Surface Water Changes

Thousands of gages that measure the flow of streams are maintained by the U.S. Geological Survey. Several such gages were in operation in the Hebgen Lake area, and gave much information about the effect of the earthquake on the streams.

The discharge of streams into the lake increased sharply after the earthquake. For example, during August 16 and 17, before the earthquake, gages on the Madison River indicated that the rate of discharge was 350 cubic feet per second. By midnight August 18, a day after the earthquake, the river was discharging water at the rate of 500 cubic feet per second. In the first 16 days of August the net flow into Hebgen Lake was 600 cubic feet per second. In the last 10 days of the month it was 1,100 cubic feet per second.

Despite the northward tilting of the Red Canyon and Hebgen Lake blocks, most streams remained in their established channels. One prominent exception was Grayling Creek, which, near the Parade Rest Ranch, was displaced northward into a former abandoned channel, flooding some pastureland and a pumphouse.

Ground Water Changes

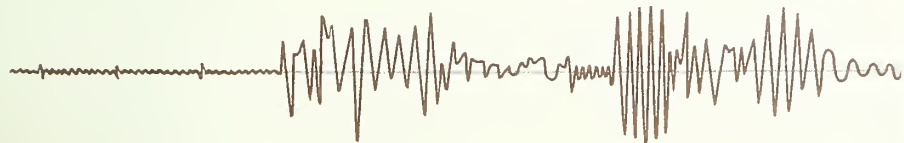
Within moments after the major shock, springs rising in volcanic rocks began to discharge into the streams large amounts of fine sediment, much of which stayed in suspension. By early morning of August 18 the water of every stream was light brown and cloudy.

After a few weeks some streams cleared, but others fed chiefly by the springs in volcanic rocks were still milky. The mouth of each stream entering Hebgen Lake was marked by a broad blotch of light brown water.

The minute particles of sediment were probably washed from the myriad cracks and crevices in the volcanic rocks. These brittle rocks were jostled by the tremors. Grating along the fractures loosened very small rock fragments, which were then picked up by ground waters that fed the springs.

The discharge from wells and springs changed erratically after the earthquake. Several springs and wells that had always been faithful suppliers of water stopped flowing, whereas others increased their flow. Springs appeared in places where none had been before, as along the south flank of Horse Butte. These new springs, rising in very ancient crystalline rocks, differed in several noteworthy respects from the other springs in the area. First, they were warmer, with a temperature of about 52° F. in contrast to the 40° F. of most springs; second, they were clear, whereas most of the other springs were cloudy with sediment; and finally, they contained extraordinarily large amounts of radon, a radioactive gas.

The earthquake caused fluctuations in the water levels in wells throughout the United States, in Puerto Rico, and as far away as Hawaii. In Idaho, near the Earthquake Area, the maximum fluctuation was as much as 10 feet. Farther south, in Utah, it was about 5 feet, and along the east coast of the United States it was about 1 foot. In Hawaii, some 3,200 miles away, the earthquake caused a minor fluctuation of about 0.1 foot in several water wells. In northeastern Pennsylvania, near Wilkes-Barre, pools of water in several coal mines fluctuated in response to the seismic shocks.



Submerged dock at "The Narrows" resort. The platform of this dock, formerly well above the water level, is now concealed under about 2 feet of water.



WHAT TO SEE IN THE EARTHQUAKE AREA



THE FAULT SCARPS

Typical fault scarps can be seen at the following sites in the Earthquake Area (index map):

Site 1—Red Canyon Fault scarp in Red Canyon

Site 5—Hebgen Fault scarp at mouth of Cabin Creek

A fault is a break in the rocks along which there has been movement. Faults in the Earthquake Area are simply identified as faults and named after geographic features, as for example "Red Canyon Fault" and "Hebgen Fault." It is clear that they are fairly old because they are partly concealed by debris and foliage. In this publication, fault scarp refers to a fresh clifflike break in the ground which appeared on the night of August 17, 1959. Generally the fault scarps coincide with or are parallel to the old faults (indicating that the fault scarps resulted from renewed movement on the faults); therefore, the new fault scarps bear the same names. The Red Canyon Fault scarp thus coincides with or is parallel to the Red Canyon Fault.

Many new fault scarps were formed during the earthquake; the larger ones are all north of Hebgen Lake, where four well-defined scarps appeared overnight. Two of these, the Red Canyon and the Hebgen Fault scarps, extend for miles; the other two are shorter.

These clifflike fault scarps face valleyward, which is always southward. From a distance the scarps appear as bright wavy lines that continue unbroken across mountains, valleys, and broad flats (p. 20).

The Red Canyon Fault scarp extends westward for about 14 miles from near the "Y" formed by highways U.S. 191 and State 287 to its end in Kirkwood Creek far to the west (index map). The Hebgen Fault scarp is about 8 miles long, and extends from near the Hebgen Lake Lodge to the east valley wall of Beaver Creek.

Everything along the fault scarps was damaged—trees were downed, trails and roads were offset, dwellings were ruined. New waterfalls were formed where streams crossed the scarps.

On the night of the earthquake, the southerly facing Red Canyon Fault scarp proved most hazardous, especially for those drivers who were traveling south, unaware that the scarp had cut across and offset route 191.

One family in a motel near the junction of routes 191 and 287, was violently awakened by the major shock. Alarmed and bewildered, they hurriedly dressed and got into their car to flee to West Yellowstone. They were hardly settled in their seats when the car hurtled across the fresh Red Canyon Fault scarp, fell 6 feet, turned over, and crashed. Amazingly, no one was badly hurt. The family crawled out of the wreckage and walked back to the cabin they had left.

A short distance away, a rancher and his family were also awakened by the major tremor. After assuring themselves that no one was injured, the family drove off to

help their neighbors. The car traveled about 100 feet before it dropped off the new fault scarp—and landed on its nose.

The main residence at the Blarneystone Ranch (index map) was astride the old Red Canyon Fault, which was concealed in this area beneath broad deposits of sand and gravel. On the night of the earthquake the major part of the house south of the fault dropped about 10 feet and was severely damaged. Part of the domestic quarters and a storage shed north of the fault were intensely shaken, and collapsed (p. 23).

The storage shed at the Blarneystone Ranch also served as a chicken coop. One hen was so unnerved by this cataclysmic destruction of her home that she laid an egg in the hands of a woman who picked her up!

The Hebgen Fault scarp appeared directly behind (north of) the cabins at the Hebgen Lake Lodge. The cabins were tilted about $2\frac{1}{2}^\circ$ to the north. Many doors and windows in the cabins jammed, but all occupants were able to force them open and escape unharmed.

Two children, asleep in one of the cabins, slept through the entire earthquake, even though their cabin dropped about 5 feet.



In several places, as along the hills north of the Grayling Arm of Hebgen Lake, the fault scarps pass into small gaping fissures which break the soil. The average fissure is about 100 feet long, 2 to 3 feet deep, gapes 2 to 3 inches at the surface, and has jagged edges. Some fissures are much larger, being as much as 1,000 feet long, 8 to 10 feet deep, and gaping as much as 2 feet at the surface.

TILTING AND WARPING OF THE SUBSIDED BLOCKS

Submerged features showing the tilting and warping of the Hebgen Lake block can be seen at the following sites in the Earthquake Area. In addition, many examples of the emerged shoreline may be seen along the south shore of Hebgen Lake.

1. Site 2—Submergent shoreline and sand spouts at mouth of Dave Johnson Creek, near Hebgen Lake Lodge.
2. Site 3—Slumping along the north side of Hebgen Lake.
3. Recommended trip to see emergent features. Take Forest Service "Basin road" to see summer homes along south shore of Hebgen Lake.

THE MADISON SLIDE

*The Madison Slide can be seen best from selected site 7
in the Earthquake Area*

The Madison Slide is one of the more awe-inspiring features in the Earthquake Area. Its immense size coupled with the huge volume of water it impounds is enough to command respect. These feelings are strengthened by the realization that this vast pile of rock was emplaced in a few moments, burying several camp areas and their occupants.

The slide is composed of three dominant rock types: (1) *dolomite*, a white to pale-red crystalline rock, (2) *schist*, a green finely laminated rock, and (3) *gneiss*, a gray faintly banded granular rock.

The dolomite, which once acted as a buttress (p. 15), now appears as a jumble of boulders along the north edge of the slide. Remnants of the once continuous dolomite buttress can still be seen as light brown jagged ridges along the lower slopes of the south valley wall (p. 15), almost directly opposite the parking area.

The remaining rocks in the slide consist of schist and gneiss, schist being the more common. The parking area and most of the footpaths are constructed on this rock.

Shortly after the slide was emplaced it became apparent that the water ponding behind it would soon drown the toe of Hebgen Dam, some 5½ miles upstream. (If this had happened, Hebgen Dam would have been

a most unusual dam, with standing water on both sides!) Also, the slide might suddenly wash out, releasing the waters of Earthquake Lake as a devastating flood on the residents downstream. A spillway had to be cut across the slide, and this was undertaken by the Corps of Engineers, U.S. Army. They soon discovered that, although the surface of the slide was formed by large boulders, the material beneath was much smaller. Fearful that this smaller material would be easily eroded, the Engineers decided to surface the spillway with dolomite boulders. Many of the roads visible on the slide are merely work routes used to bring the dolomite boulders to the spillway.

Once the spillway was completed, and waters released through it, the downstream edge of the spillway began to fray and erode back—a clear indication that the grade of the spillway was too steep. The broad deposits of gray rock that fringe the west edge of the slide (near the entrance to the slide) were formed at this time. The fraying was halted by cutting a new spillway at a lesser grade along the centerline of the old spillway. This new spillway, some 50 feet deep, now carries the waters of Earthquake Lake across the slide. After the cutting of this new spillway, the lake level dropped 50 feet, leaving dead branches and trees as reminders of the former waterline.

The volume of water that flows through the Madison Slide spillway is controlled by the spillway at Hebgen Dam—some 5½ miles upstream!

Damage to Blarneystone Ranch. The main residence was astride the Red Canyon Fault and was severely damaged when the fault moved again. Top left: Structural damage to walls of the main residence. Top right: The fault scarp where it cuts across Grayling Creek and extends toward the main residence. Fault scarp gives way at base of tree-covered hill to small fissures which break surficial cover. Bottom: The fault scarp where it passes beneath the dwellings. The buildings to the right of the scarp have collapsed; the buildings to the left have dropped about 10 feet.



SELECTED SITES IN THE EARTHQUAKE AREA

The Forest Service has selected seven sites where the results of the earthquake are especially well exposed. These sites, and how to reach them, are shown on the index map. Listed below are some of the more interesting features to be seen at each site. Numbers in parentheses refer to pages where these features are discussed.

Site 1.—*The Red Canyon Fault scarp*

- a.—Waterfall across scarp (p. 21).
- b.—Fissures and ground cracks (p. 22).
- c.—Fallen trees, rockfalls, slumped ground (p. 8).
- d.—About 1,000 feet north of the scarp, the Forest Service trail crosses bedded rocks that are steeply dipping or even turned over.

Site 2.—*Sand spouts and submerged north shore near Hebgen Lake Lodge*

- a.—Large sand spouts and craters (p. 16).
- b.—Submerged shoreline, drowned willows, etc. (p. 9).

Site 3.—*Landslide of part of former highway 287 into Hebgen Lake*

- a.—The scalloped alcove formed when part of highway 287 slid into the lake (p. 17).

- b.—Hebgen Fault scarp. The scarp is in the woods about 100 feet above the road (p. 21).
- c.—Submerged shoreline (p. 9).

Site 4.—*Hilgard Lodge*

- a.—Party submerged motel units (p. 9).
- b.—Seiche marks (p. 10).
- c.—Ground fissures (p. 9).
- d.—Destroyed main residence, about 200 yards west of the motel units (p. 10).

Site 5.—*Hebgen Fault scarp at mouth of Cabin Creek*

- a.—Waterfall across scarp (p. 21).

Site 6.—*Earthquake Lake*

- a.—Northern edge of Earthquake Lake (p. 11).

Site 7.—*The Madison Slide*

- a.—Dolomite ridge along the north edge of the slide (p. 14).
- b.—Source area of slide, south valley wall (p. 14).
- c.—Earthquake Lake (p. 16).
- d.—Spillway across the Madison Slide (p. 22).
- e.—Various rock types that make up bulk of slide (p. 22).
- f.—New alluvial fan formed at mouth of the Madison River Canyon, due to the erosion of the Madison Slide (p. 22).



